



**UNIVERSITI PUTRA MALAYSIA**

**PEEL STRENGTH AND OTHER RELATED  
MECHANICAL PROPERTIES OF COMPOSITE  
SANDWICH STRUCTURES**

**ZAHURIN BINTI HALIM**

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**PEEL STRENGTH AND OTHER RELATED MECHANICAL PROPERTIES OF  
COMPOSITE SANDWICH STRUCTURES**

**By**

**ZAHURIN BINTI HALIM**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirement for the Degree of Doctor of Philosophy**

**November 2002**



**To My Husband, Parents, Family and Friends**

Thank you for being my inspiration and motivator....

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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**November 2002**

**Chairman: Professor ShahNor Bin Basri, Ph.D, PEng**

**Faculty: Engineering**

An experimental and numerical investigation of the peel strength and other mechanical properties of composite sandwich structures were conducted. The composite sandwich structure consists of carbon fibre and aramid fibre as facings with either a honeycomb or foam core.

The peel strength of both types of composite sandwich structure for use at the flap and aileron was studied. The peel tests showed that the composite sandwich structure with a honeycomb core is stronger than the composite sandwich structure with a foam core. The modes of failures or possible path of crack propagation were also studied. The most critical modes of failure were the adhesion failure to the facing and the adhesion failure to the core.

A peel modelling was developed using interface elements and the effect of various modes of failures on the strain energy release rate was evaluated by finite element analysis using LUSAS, a commercial finite element code. A numerical scheme called

virtual crack closure scheme was used to calculate the strain energy release rate at the peel front in a peel test specimen.

To complement the results on the peel strength, investigations on other related mechanical properties were conducted and comparisons were made with previous works in the reference. The important parameters studied were bending, shear and compression as all of them has a static condition. The results show that experimental, numerical and validations with parametric studies agree well. The tensile test was also conducted experimentally to obtain modulus of elasticity that was required in the computational calculations.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

**KEKUATAN LEKANG DAN SIFAT-SIFAT MEKANIKAL YANG  
BERKAITAN UNTUK STRUKTUR KOMPOSIT TERAPIT**

**Oleh**

**ZAHURIN BINTI HALIM**

**November 2002**

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Kajian eksperimen dan berangka telah dijalankan ke atas kekuatan lejang struktur komposit terapis. Struktur komposit terapis tersebut terdiri daripada gentian karbon dan gentian aramid sebagai permukaan atas dan samada busa atau indung madu sebagai teras. Dua bahagian yang paling dipengaruhi oleh kesan lejang di dalam sesebuah kapal terbang adalah aileron dan kepak dan kajian terperinci ke atas kedua-dua bahagian dijalankan.

Ujian lejang telah menunjukkan bahawa struktur komposit terapis dengan teras indung madu adalah lebih kuat daripada struktur komposit terapis dengan teras busa. Mod kegagalan atau laluan yang mungkin bagi perambatan retak juga telah diselidiki. Mod kegagalan yang paling kritikal adalah kegagalan rekatan pada permukaan atas serta kegagalan rekatan pada teras.

Model baru untuk proses lejang dengan menggunakan elemen antaramuka telah dibangunkan dan kesan pelbagai mod kegagalan ke atas kadar pelepasan tenaga terikan telah dinilai dengan menggunakan kaedah analisis unsur terhingga dengan

menggunakan kod komersil analisis unsur LUSAS. Skim berangka yang dipanggil skim penutupan retak maya digunakan untuk mengira kadar pelepasan tenaga terikan pada permukaan hadapan lekang dalam spesimen ujian lekang.

Kajian ke atas sifat-sifat mekanikal yang lain dijalankan untuk mensahihkan model lekang dan perbandingan dibuat dengan kajian-kajian terdahulu dalam rujukan. Parameter penting yang dikaji adalah lenturan, ricihan dan mampatan. Daripada keputusan yang diperolehi, ianya menunjukkan bahawa kajian eksperimen, kajian berangka dan kajian sifat-sifat mekanikal untuk pengsahtihan adalah sepakat. Ujian tegangan juga dijalankan secara eksperimen untuk memperolehi modulus elastik yang diperlukan dalam pengiraan berangka.

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I certify that an Examination Committee met on 28 November 2002 to conduct the final examination of Zahurin Halim on his Doctor of Philosophy thesis entitled "Peel Strength and Other Related Mechanical Properties of Composite Sandwich Structures" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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## DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

  
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Date: 17 DEC. 2002

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## LIST OF ABBREVIATIONS

$A_f$	net cross-sectional area of fibre
$A_i$	cross-sectional area of lamina i
$A_m$	net cross-sectional area of matrix
$D$	flexural rigidity
$E$	modulus of elasticity
$E_{11}$	longitudinal elastic modulus of composite facings
$E_c$	modulus of elasticity of the core
$E_f$	modulus of elasticity of the facings
$E_{fi}$	fibre Young's Modulus
$E_i$	modulus of elasticity of lamina I
$E_m$	matrix Young's Modulus
$E_x$	modulus of elasticity of lamina at distance x from neutral axis
$F(\sigma)$	yield surface
$F_1(\sigma)$	limited tension criterion
$F_2(\sigma)$	Mohr-Coulomb criterion
$F_o$	load required to overcome resisting load
$F_p$	average load required to bend and peel adherend
$G$	strain energy release rate
$G_c$	shear modulus of core
$I$	second moment of area
$I_i$	second moment of area of lamina I about neutral axis

$L$	beam length
$M$	bending moment
$N$	shear stiffness of core
$N_i, \xi, \eta$	element shape function
$P$	peel strength
$\underline{P}$	vector of internal forces
$\underline{P}_b$	vectors of the bottom displacements
$P_{cr}$	critical buckling load
$P_{ec}$	edge compressive load
$P_p$	point load
$\underline{P}_t$	vectors of the top displacements
$P_t$	tensile force
$Q$	shear force
$S$	first moment of area
$U$	strain energy in the facing at the strain $\varepsilon_{11}$
$U, V$	the nodal degrees of freedom
$W$	work
$W_k$	mid-ordinate integration weights
$\underline{\underline{B}}$	strain displacement
$\underline{\underline{B'}}$	local strain global displacement
$\underline{\underline{D}}$	stiffness matrix
$\underline{\underline{D'}}$	matrix of elastic properties

$\underline{\underline{H}}$	shape function matrix
$\underline{\underline{J}}$	Jacobian matrix
$\underline{\underline{K}}$	element stiffness matrix
$\underline{R}$	load vector
$\bar{x}$	neutral axis location
$1/R$	curvature
$\underline{a}$	global displacement
$a$	spacing between points of honeycomb core support for the facings
$b$	width of beam
$c$	thickness of the core
$c_s$	cohesive strength
$d$	distance between the centre lines of the upper and lower facings
$f$	thickness of the facing
$h$	overall depth of the beam
$h_k$	thickness of the $k^{\text{th}}$ layer
$k_b, k_s$	constants dependent on the beam loading
$k_d$	theoretical or experimental dimpling coefficient
$k_w$	theoretical or empirical buckling coefficient
$r_i$	radius of drum
$r_o$	radius of flange
$t$	the total thickness of the shell
$\underline{u}$	displacement field
$\underline{u}_b$	bottom displacement

$\underline{u}_t$	top displacement
$v_f$	fibre volume fraction
$v_m$	matrix volume fraction
$w$	width of the facing
$z$	depth below the centroid of the cross-section
$\alpha$	peel angle
$\delta$	deflection
$\epsilon_{11}$	tensile strain in fibre direction in the facing
$\epsilon_c$	longitudinal strain in composite
$\epsilon_m$	longitudinal strain in matrix
$\underline{\epsilon}, \underline{\sigma}$	total strains and stresses
$\underline{\epsilon}', \underline{\sigma}'$	local strain and stress vector
$\underline{\epsilon}_0, \underline{\sigma}_0$	initial strains and stresses
$\phi$	friction angle
$\lambda$	an angle of orthotrophy
$\nu$	Poisson's ratio
$\nu_c$	Poisson ratio of core
$\nu_f$	Poisson ratio of faces
$\sigma_{11}$	tensile stress in fibre direction in the facing
$\sigma_{co}$	average tensile stress in the composite
$\sigma_{fi}$	fibre stress
$\sigma_m$	matrix stress
$\sigma$	bending stress

$\sigma'_c$	compressive stress in core
$\sigma'_f$	compressive stress in faces
$\sigma_c$	bending stress in core, at extreme fibre
$\sigma_f$	bending stress in faces
$\sigma_n$	compressive stress in core
$\sigma_t$	threshold strength
$\sigma_w$	wrinkling of compressive force
$\tau$	shear stress
$\tau_c$	shear stress of the core
$\xi, \eta, \zeta$	parent coordinates in a mapped element
$\xi_k$	within the $k_{th}$ layer of an element
$\underline{\Psi}$	residual force vector



# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Structural materials can be divided into four basic categories: metals, polymers, ceramics and composites. Composites, which consist of two or more separate materials combined in a macroscopic structural unit, are made from various combinations of the three materials. For over 60 years, composite materials have proven to be very successfully utilized in structural applications. They are used in stiffness-critical aerospace structures, offshore structures, marine, automotive industries and also in medical, sports and electrical applications.

Composite materials can be divided into two main groups i.e. particle composites and fibre-reinforced composites. The detailed types of composite construction are shown in Figure 1.1[1]. In this present work only composite sandwich structures will be discussed thoroughly. The American Society for Testing and Materials (ASTM) defines for a composite sandwich structure as a construction which consists of high strength composite facing sheets bonded to a lightweight foam or honeycomb core as shown in Figure 1.2[2].